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FORAGE QUALITY OF RILLSCALE (*ATRIPLEX SUCKLEYI*) GROWN ON AMENDED BENTONITE MINE SPOIL

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ABSTRACT.—At peak standing crop, rillscale (*Atriplex suckleyi*) foliage grown on amended bentonite mine spoil contained adequate digestible energy, crude protein, and all mineral elements except phosphorus necessary for cattle, sheep, antelope, and deer. Amendments (sawdust, NPK, gypsum) generally did not affect forage quality. Iron, manganese, aluminum, sodium, and potassium concentrations were high and may have adversely affected forage quality. Forage utility would be limited to a few months during the growing season.

Atriplex suckleyi (Torrey) Rydb., commonly called rillscale, is the dominant native invader on bentonite mine spoil (Sieg et al. 1983). Rillscale is a spreading annual plant, usually less than 30 cm in height, that flowers from early June to mid-August, bearing mature seed before the end of July. The plant is found only in southern Saskatchewan, southern Alberta, Montana, Wyoming, North Dakota, South Dakota, and Nebraska. It has been observed that the plant grows in saline, clayey, and alkaline land "where nothing else seems to grow" (Frankton and Bassett 1970). Little in known about the biology of this species.

Forage quality is an important consideration in the selection of species for use in revegetation of bentonite mine spoil, since grazing is the major postmining land use in regions where bentonite is mined. Wildlife forage and habitat are also emphasized in reclamation efforts. Twenty-two species of wildlife are known to use *Atriplex* species for food and cover (Robinette 1971, Martin et al. 1951). *Atriplex* species are valued by range managers because of their high protein content (Bidwell and Wooton 1925).

The peak forage value of rillscale, as with most annual forbs, is in all likelihood limited to spring and early summer months (Cook 1972, Stoddart et al. 1975). When available, it may make an important contribution to the nutrition of livestock and wildlife. The objective of this study was twofold: (1) to examine chemical properties of rillscale foliage collected from plots on raw bentonite spoil and on bentonite spoil that had been amended with various combinations of gypsum, fertilizer (NPK), and sawdust during the year prior to harvest; and (2) to assess the effects of treatments on growth of rillscale during the year following treatment.

METHODS

Study Area and Treatments

The study area is located just west of the central Black Hills near Upton, Wyoming, on the Mowry shale formation. Sagebrush (*Artemisia tridentata*) is the predominant vegetation on this grassland, with scattered stands of ponderosa pine (*Pinus ponderosa*). Annual precipitation averages 350 mm (National Oceanic and Atmospheric Administration 1981), falling mostly during the growing season from May to September. Soils are generally shallow and poorly developed.

An area was selected on unreclaimed bentonite mine spoil that was mined before 1968 on the property of American Colloid. The experimental design was that of a 2^3 factorial arrangement of treatments with each of three spoil amendments at two levels (Voorhees et al. 1987). One level was the absence of each amendment, while the other level was the presence of the amendment.

The study site was rototilled to a depth of approximately 5 cm, and gypsum was applied at a level of 31 metric tons per hectare. Introduction of Ca^{++} in the form of $CaSO_4$ was

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intended to facilitate exchange with monovalent sodium, which would encourage flocculation and water penetration (Brady 1974) and discourage surface crust formation. Fertilizer was added at the rate of 114 kg nitrogen, 23 kg phosphorus, and 50 kg potassium per hectare. Nitrogen and phosphorus were added as ammonium nitrate (NH_4NO_3) and diammonium phosphate ($(NH_4)_2HPO_4$). Potassium was added as potassium chloride (KCl). Sawdust was added at the ratio of one part sawdust to two parts spoil (by volume). Inorganic nitrogen (NH_4NO_3) corresponding to 0.6% of sawdust (by weight) was added to the sawdust before mixing with spoil to prevent a large increase in the carbon-to-nitrogen ratio and subsequent tie-up of soil nitrogen by microorganisms (Allison 1965). This amount of nitrogen corresponded to 6 kg nitrogen per metric ton of sawdust. The sawdust amendment was intended to increase structural stability and tilth of spoil as well as air and water permeability (Voorhees et al. 1983, 1987). The effects of organic matter additions in the form of sawdust might be expected to increase the stability of the substrate where organic matter is less than 2% (Marshall and Holmes 1979) as in bentonite mine spoil (Uresk and Yamamoto 1986).

Gypsum and sawdust amendments were manually incorporated into tilled spoil, whereas the fertilizer amendment was applied to the surface. All eight combinations of the three amendments, including control, were replicated twice to give a total of 16 plots, each 60 × 150 cm. The plots were tilled, amended, and seeded on 8 May 1982. Plots were self-seeded in 1983 as no seed was planted that year.

Rillscale seed, obtained from sites along the Montana-Wyoming border during late summer of 1980, was planted in each plot so that seed weights corresponded to approximately three live seeds per cm^2. This weight of seed was calculated from total percentage germination and seed density determinations made within six weeks of planting. Seed was broadcast on the surface and raked (1 cm) into spoil.

One-half of each plot was harvested for chemical analysis by manually cutting off stems at ground level during estimated peak standing crop (7 July 1983). The other half was harvested approximately six weeks after estimated peak standing crop (17 August 1983) to determine the rate of decline in standing crop resulting from drying and shattering of foliage as the season progressed. It was assumed that harvesting one-half of each plot had an insignificant effect on plants on the remaining half. All harvested biomass was oven-dried at 55 C, weighed, and ground through a 20-mesh screen.

Plant Tissue Analyses

Plant tissue analyses included total nitrogen by conventional micro-Kjeldahl, in-vitro, dry-matter digestibility, and percentage ash (Church and Pond 1978). Duplicate samples of plant tissue were analyzed to determine nitrogen, ash, and dry-matter digestibility. Dry-matter digestibility was determined with acid pepsin using two 48-hour digestions in a rumen buffer solution taken from cattle eating grass hay (Tilley and Terry 1963). Crude protein percentage was estimated from Kjeldahl nitrogen ($CP = N\% \times 6.25$). Digestible energy (DE) was estimated from dry-matter digestibility values (Rittenhouse et al. 1971) and converted to metabolizable energy (ME) (Mcal/kg dry matter) using the following formula (Swift 1957):

$$DE(Mcal/kg) \times 0.79 = ME(Mcal/kg).$$

Elemental concentrations of nitric acid–extractable aluminum, arsenic, barium, boron, cadmium, calcium, chromium, copper, iron, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, selenium, sodium, strontium, titanium, and zinc were determined for the plant tissue. Samples were analyzed in duplicate; checks (standards) and blanks were included. Elemental concentrations of nitric acid extracts were measured using inductively coupled plasma atomic emission spectrometry (ICP-AES) (Fassel and Kniseley 1974, Jones 1977) on the nitric acid digestion (Havlin and Soltanpour 1980, Gestring and Soltanpour 1981).

Statistical Analysis

A three-way factorial analysis of variance was used to determine the effects of spoil amendments (gypsum, sawdust, and fertilizer) and associated interactions on each foliage property. Significant differences were accepted at the .05 probability level.

TABLE 1. Chemical composition of the foliage of rillscale grown on bentonite mine spoil averaged across treatment that did or did not include amendment with sawdust, NPK fertilizer, or gypsum.

Property (units)	Sawdust without	Sawdust with	NPK without	NPK with	Gypsum without	Gypsum with
Standing crop (kg/ha)	955*[1]	1,973	1,297	1,631	1,534	1,394
Dry-matter digestibility (%)	73	72	73	72	73	73
Digestible energy (kcal/kgDM)[2]	2,968	2,923	2,970	2,920	2,954	2,955
Metabolizable energy (Mcal/kgDM)	2.35	2.31	2.35	2.31	2.32	2.33
Kjeldahl nitrogen (%)	1.70*	1.87	1.74*	1.83	1.74	1.83
Crude protein (%)	11*	12	11	12	11	12
Ash (%)	42*	35	40	37	38	39
Ca (%)	0.47	0.43	0.45	0.45	0.43	0.47
Mg (%)	0.99	0.92	0.98	0.94	0.96	0.95
P (%)	0.19	0.17	0.18	0.18	0.18	0.18
Ca:P	2.55	2.57	2.65	2.47	2.47	2.64
Na (%)	8.55	8.18	8.30	8.43	8.63	8.11
K (%)	1.13	1.10	1.11	1.12	1.12	1.11
Zn (μg/g)	66	63	61	68	55	74
Fe (μg/g)	10,775	11,128	9,924	8,188	3,999	10,775
Mn (μg/g)	496	297	450	343	332	461
N (μg/g)	8	6	8	7	7	8
Cr (μg/g)	5	5	5	5	5	5
Cu (μg/g)	7*	6	6	6	6	7
Mo (μg/g)	16	17	21	13	17	16
Cu:Mo	0.5	0.5	0.5	0.4	0.4	0.5
B (μg/g)	35*	41	37	39	39	37
Al (μg/g)	1,296*	1,006	1,176	1,126	938*	1,365
Ba (μg/g)	37	32	35	34	28	41
Sr (μg/g)	69	73	72	69	68	73
Ti (μg/g)	10	8	9	9	8*	10

[1]Means for each property that are followed by an asterisk (*) are significantly different ($p > .05$).
[2]Based on in-vitro, dry-matter digestibility.

RESULTS

Peak standing crop averaged 1,464 kg dry matter per hectare (Table 1) and ranged from 267 to 2,913 kg dry matter per hectare. Peak standing crop was 107% greater and ash averaged 17% lower on plots that had been amended with sawdust (alone or in combination with other amendments) than on plots that had not been amended with sawdust. Standing crop decreased without grazing by 21% from early July to mid-August.

Digestible energy of rillscale foliage at peak of standing crop (based on IVDMD) was 2,948 kcal/kg dry matter (Table 1). Digestibility of dry matter and estimates of digestible and metabolizable energy levels were all significantly decreased when sawdust and fertilizer were used in combination (with or without the gypsum amendment) relative to the use of other combinations of amendments.

Crude protein of rillscale foliage ranged from 9 to 14%. Amendment of spoil with sawdust (alone or in combination with other amendments) significantly increased the concentration of nitrogen in foliage from 1.70 to 1.87% and increased the crude protein rating from 11 to 12% relative to foliage on spoil not amended with sawdust (Table 1).

Calcium and magnesium levels in rillscale foliage averaged 0.45 and 0.96%, respectively (Table 1). The level of phosphorus was 0.18%, and the ratio of calcium to phosphorus was 2.6:1. Levels of sodium and potassium in rillscale foliage were 8.37 and 1.12%, respectively. When sawdust and fertilizer amendments were used in combination (with or without the gypsum amendment), the foliar content of magnesium and potassium decreased relative to concentrations in foliage on spoils amended with either of these two amendments alone.

Zinc levels in rillscale foliage averaged about 65 μg/g (Table 1). Iron and manganese levels were 9,131 and 397 μg/g, respectively. Nickel levels averaged 7 μg/g, whereas chromium levels were 5 μg/g.

The concentration of copper in foliage was 6 μg/g, while molybdenum concentration was 17 μg/g (Table 1). The sawdust amendment (alone or in combination with other amendments) decreased foliar copper from 7 to 6 μg/g but did not significantly alter the ratio of copper to molybdenum.

High levels of aluminum and iron in rillscale foliage caused severe spectral interferences for arsenic and selenium; thus, it was not possible to determine the concentrations of these elements.

Foliar aluminum levels ranged from 1,000 to 1,300 μg/g. The gypsum amendment (alone or in combination with other amendments) significantly increased foliar aluminum levels from an average of 938 to 1,365 μg/g (Table 1) relative to foliage on spoil that had not been amended with gypsum. Amendment of spoil with sawdust (with or without other amendments) resulted in a decrease in the concentration of aluminum in foliage compared with foliage from spoil not amended with sawdust.

Cadmium levels in rillscale foliage were below detection limits (1.0 μg/g) for the ICP-AES procedure. Boron concentrations in foliage averaged 38 μg/g and were significantly greater when sawdust was added to spoil (with or without other amendments) than they were in foliage grown on spoil not amended with sawdust (Table 1).

Barium levels in foliage averaged 35 μg/g, while strontium concentrations averaged 71 μg/g. When sawdust and fertilizer amendments were used in combination (with or without the gypsum amendment), strontium levels were greater than when either of these amendments was used alone.

Titanium concentrations in foliage averaged 9 μg/g and increased by 25% when gypsum was added (with or without other amendments) relative to foliage from spoil not treated with gypsum (Table 1).

The fertilizer amendment (with or without other amendments) had little effect on foliar composition (Table 1) except through interaction with the sawdust amendment.

DISCUSSION

The forage utility of rillscale as an annual forb is probably limited to a few months during the growing season, culminating with peak of growth in late June and rapidly declining thereafter. Late in the growing season most species of forbs fail to meet the protein and energy needs of gestating animals and are considered inadequate as forage after the fruiting stage (Cook 1972, Stoddart et al. 1975).

The quantities of forage available from growth of rillscale on spoil would be inadequate for most grazing uses except during a few months of the year. Standing crop declined by 21% without grazing from early July to mid-August. This decline following maturity was attributed to drying and shattering of foliage. No evidence of grazing by insects was observed. However, rillscale could make an important contribution to the nutrition of livestock and wildlife during the short period of time it is growing and available. Other plant species could be planted with rillscale (Uresk and Yamamoto 1986, Welch 1989) to help meet the nutritional requirements of herbivores.

The sawdust amendment increased standing crop and decreased ash by improving plant-water relations and increasing the availability of nitrogen. Increased availability of water reduces plant requirements for salts; conversely, plants under water stress accumulate other nutrients when nitrogen is limiting (Mengel and Kirkby 1982). Decreases in plant ash as a result of the sawdust amendment would account for significant decreases in plant uptake of copper and aluminum.

The foliage of rillscale at peak standing crop contained adequate digestible energy (based on IVDMD), crude protein percentage, and concentrations of all mineral elements except phosphorus for cattle, sheep, and wild ruminants (National Research Council 1975, 1984, Dean 1980, Stone et al. 1983). The sawdust amendment (either alone or in combination with other amendments) resulted in an increase in the concentrations of nitrogen and crude protein, while addition of both sawdust and fertilizer (with or without the gypsum amendment) decreased dry-matter digestibility and estimated digestible and metabolizable energy.

Phosphorus supplementation would be advisable for animals foraging on bentonite-mined lands revegetated with rillscale. Calcium levels exceeded most dietary requirements of livestock (National Research Council 1975, 1984, Welch 1989) but were marginal for deer (Dean 1980). Adequate fresh water at low salinity levels would also be necessary, since rillscale contains high quantities of sodium and potassium. Toxicities of electrolytes are considered unlikely unless water intake is restricted or water is highly saline (Church and Pond 1978). Iron, manganese, and aluminum were also present in very high concentrations in the foliage of rillscale, which may depress cellulose digestion (National Research Council 1984, Martinez and Church 1970, Grace 1973). Amendment of spoil with gypsum increased, whereas addition of sawdust decreased, the concentration of foliar aluminum, an important consideration because aluminum can cause gastrointestinal irritation or produce rickets by interfering with phosphate absorption if present in large quantities in the diets of some animals (Underwood 1977). Finally, the copper-to-molybdenum ratio of the foliage of rillscale was low at 0.7 and could cause molybdenum-induced copper deficiencies in livestock and wildlife that do not have access to copper supplements or forages high in copper concentration (Miltmore and Mason 1971, Stone et al. 1983). Other micro- and macro-minerals were adequate to meet the requirements of most herbivores.

The fertilizer treatment (with or without other amendments) had little effect on foliage composition, except through an interaction with the sawdust amendment. The fertilizer amendment may have been ineffective for increasing the availability of nitrogen, phosphorus, and potassium in spoils, or other conditions may have inhibited uptake of these ions. Added nutrients were probably not leached below rooting depth since permeability of unamended spoil is extremely low. Loss of fertilizer as runoff may have been a factor and thus would explain the interaction between fertilizer and sawdust amendments, since sawdust amendment has been shown to increase infiltration and decrease runoff (Voorhees 1986). Alternately, these elements might not have been limiting to plant growth. The latter hypothesis seems unlikely because the sawdust amendment was effective for increasing the level of foliar nitrogen.

Rillscale would be a good choice to consider in revegetating bentonite mine spoils because it provides substantial quantities of forage and nutritional qualities generally adequate to meet requirements of livestock and wildlife. For the few nutritional inadequacies and toxicities of rillscale, introduction of other plants on bentonite spoils may be feasible. Also, grazing native vegetation of the surrounding area should be encouraged.

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